Constraining Diffusivity and Critical Slope from Post-Fire Sediment Flux of the Day, Canyon, and Corral Fires, California

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One of the primary effects of wildfire on steep hillslope processes is a dramatic acceleration of sediment transport rates by dry ravel, grainflow and overland flow. These processes deliver sediment to valley bottoms where they become source material for debris flows initiated during subsequent intense rainfall. We used sediment traps to study the variation in post-fire transport rates in steeplands burned by the 2006 Day fire in the western Transverse Ranges and the 2007 Canyon and Corral fires of the Santa Monica Mountains of southern California. Within 2 to 4 weeks following fire containment, we installed 15 sediment traps on relatively planar hillslopes with gradients of 0.30 to 0.91. Mesozoic plutonic rocks and Miocene sediments produced a range of material with a median grain size of 40 to 60% sand. We observed active dry ravel and grain flows of cohesionless granular material occurring in response to localized turbulent wind bursts and solar-driven thermal variations. We visited these sites following storms that generated overland flow transport during high-intensity precipitation. Tipping-bucket rain gages provided precipitation data and nearby anemometers provided wind direction and speed.

To estimate unit sediment flux, we air dried the samples and divided the total mass accumulated per time interval by the trap width. Flux ranged over 3 orders of magnitude, from 0.001 to 1.3 $m^{-3}m^{-1}yr^{-1}$, lower on gentle slopes and higher on steeper slopes, independent of parent material. Flux rates decline monotonically with time since fire. A plot of flux versus hillslope gradient can be fit with a non-linear exponential relation used by other researchers to model steep hillslope transport rates. At Day fire sites, values of critical hillslope gradient (Sc), where the flux becomes infinite in a non-linear transport law, remained constant at 0.77 throughout the 18-month observation period. The diffusivity (K) declined from 0.03 (2 months post-installation) to 0.008 (18 months post-installation) $m^2 day^{-1}$. Five traps in the Canyon and Corral fire sites were fit with a 0.72 critical slope and a 0.03 $m^2 day^{-1}$ diffusivity for the time-frame of 2 months post installation, values similar to the Day fire sites. Three sites at the Canyon and Corral fires showed signs of sediment supply or process effects on their flux rates. These steepest sites (0.79-0.91 slope) were located several meters downslope from rock outcrops and had flux rates characteristic of lower slope sites in less supply-limited reaches. These low rates may represent reduced flux rates from small source lengths and close proximity to bedrock outcrops where rockfall, not grain flow, is the dominant transport process.

At all sites, the largest amount of hillslope transport occurred prior to the arrival of the greatest amount of precipitation. Reductions in post-fire sediment flux and diffusivity values are consistent with field observations documenting that initially soil-mantled hillslopes were gradually stripped to bedrock and converted from transport-limited to supply-limited conditions. Furthermore, a time-series of terrestrial LiDAR surveys documented the gradual infilling of low-order valleys by as much as 1 m of sediment and that small frictional dams formed by the regrowth of vegetation provided effective traps and a mechanism to rapidly decrease diffusivity. Hence, high rates of transport in landscapes disturbed by fire can be quickly modulated through decreased sediment availability and the progressive trapping efficiency of densely spaced chaparral vegetation regrowth.